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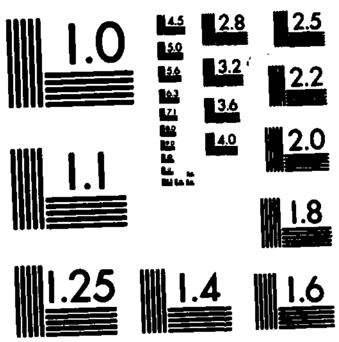

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FOREWORD

This report documents a review of the literature on human memory and information processing systems. This work was performed at the Naval Weapons Center, China Lake, California between October and December 1980, as part of the NAVAIR Human Factor's Exploratory Development Program. Funding for this effort was provided under AIRTASK A340-340F/001B/1F57/525-000 under the direction of Dr. Julie Hopson, Naval Air Development Center. This report provides preliminary working level information and is subject to review and modification.

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Head, Targeting Division
Aircraft Weapons Integration Department
31 December 1981

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MEMORANDUM OF TRANSMITTAL

From: Commander, Naval Weapons Center
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1. The enclosed publication, NWC Technical Memorandum 4605, Human Information Processing Guidelines for Decision-Aiding Displays, is provided for entry into the DTIC data base. Although the author did not opt to write the report in the format we normally follow for the retrievable literature, he did agree after publication to forward a copy to DTIC.

Elizabeth Babcock
ELIZABETH BABCOCK
By direction

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INTRODUCTION

Decision-aiding is one means of alleviating the high workload and time constraints typical of combat situations. The purpose of a decision-aid is to reduce the operator's information processing load while structuring the problem so that the operator can make the final choice. As opposed to automation, the operator is not replaced in the decision loop, instead he is freed from complex computational, memorial and processing requirements allowing him to concentrate on the consequences of the action he selects.

This report is the result of a literature search of human information processing research. The purpose was to provide baseline data from which decision-aid design guidelines could be developed. A decision aid does not replace the operator but rather interacts with the operator as part of a decision-making system, therefore some indication of how the human processes and remembers information is necessary in order to design such an aid ~~(see Appendix A)~~. The general outline of the report will consist of two major areas: (1) human memory systems and (2) human processing systems. The design guidelines that have been extracted from these studies are preliminary in nature. Their purpose is to suggest certain design concepts rather than to serve as design specifications.

HUMAN MEMORY SYSTEMS

GENERAL DESCRIPTION

The purpose of this section is to give a general description of the human memory system. The basic structure of the human memory system is illustrated in Figure 1. The flow diagram shows how information is put into various memory systems and also how these systems are interrelated. Not all the boxes represent memory systems. For example, it is necessary to discuss scanner and encoder mechanisms as intermediate steps necessary to take sensory data from the visual register and store it as meaningful information in short term memory (STM). STM is referred to as active memory while long term memory (LTM) is considered passive memory. This emphasizes the fact that items that are important to the current processing task are being stored in STM whereas the human operator's general knowledge is stored in LTM. It should be emphasized

that the precise structure of the human memory is a matter of some debate. (For more detailed discussion of the issues raised here see Broadbent, 1971; Kintsch, 1980; Murdock, 1980; Norman, 1968, 1973.)

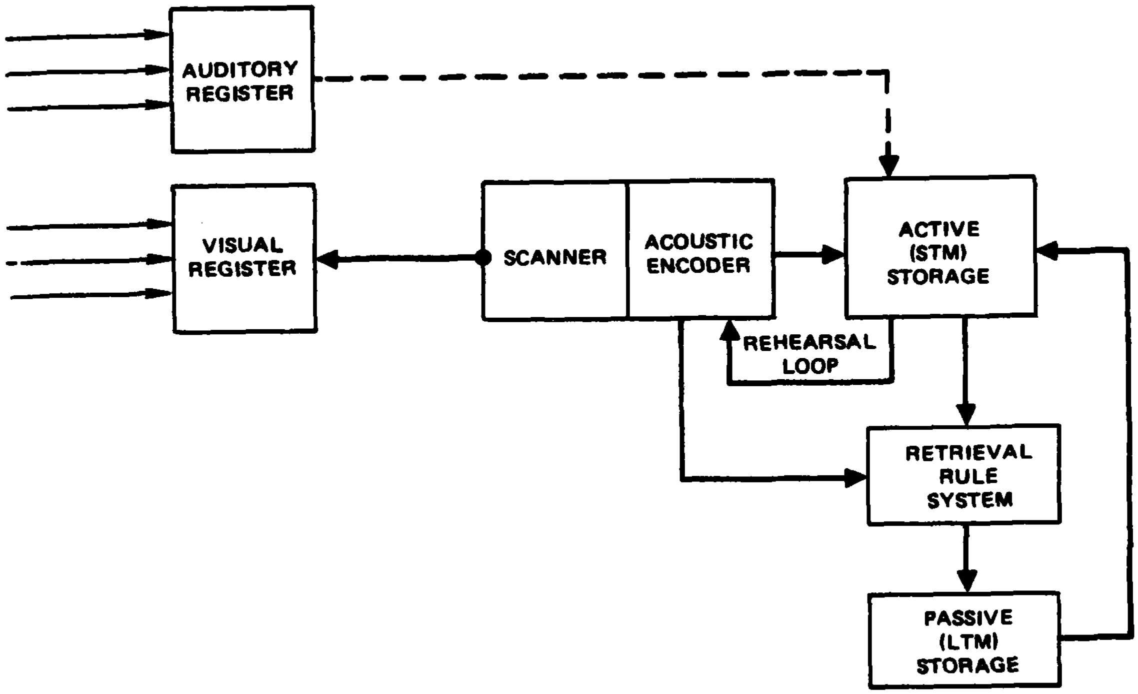

FIGURE 1. An Overview of Human Memory Systems.

Sensory Registers

As shown in Figure 1, sensory data are briefly stored on sensory registers before being processed. This information is available to the human operator from one-half to a full second after stimulus cessation (Sperling, 1960, Posner, 1967). It has been shown that this information can be masked (i.e., blocked out) if information in the same spatial field follows it in quick temporal succession (Sperling, 1962; Averbach and Corriel, 1961). There are two sensory registers shown in Figure 1, one for auditory material and one for visual material since these are the two principal channels of information for humans.

Scanner

Visual material, which have names attached to them (digits, letters, words, etc.), are scanned off the register and can be acoustically encoded as names before being stored in STM (Conrad, 1964). However, much of the material on the register is never stored and is only processed to the extent that it is checked for importance (Norman, 1969). Visual images can be stored in STM, but less is understood about this process. In most situations, the visual image lasts for a second or so and is particularly prone to be interrupted by additional mental activity (Posner, Boies, Eichleman and Taylor, 1969). Scanning material off the register to be encoded is time-consuming, and during heavy workload situations, important information can be lost because its image on the register fades. Cueing the most important items allows the scanner to selectively take this information from the register for encoding before its image fades (Sperling, 1960).

Short Term Memory

After encoding, items are stored in STM while further processing takes place. Also, more complex representations are stored in STM. Baddeley and Lieberman (1980) identified what they referred to as spatial working memory as a component of STM. This component involves temporary storage of representations of spatial relationships among objects. It has particular characteristics which will be discussed in a later section.

STM is a limited capacity system capable of storing somewhere around seven items (Miller, 1956). However, the number of items held concurrently in STM can be extended in a number of ways. One of the most efficient is to simply recode items into a smaller number of multidimensional categories (Miller, 1956). This is called "chunking" and consists of assigning more than one item to a code and remembering only the coded items.

Besides having limited storage capability in STM, memory traces are forgotten shortly if no further processing takes place. Rehearsal is a special type of processing whose only purpose is to keep items in memory. For verbal items, the operator rehearses by silently repeating the items to himself. This is illustrated by the Feedback Loop (Figure 1) from STM to acoustic encoding suggesting that this process can be repeated indefinitely in order to keep items in store. Posner (1967) suggests that rehearsal for visual images consists of concentrating on the image.

Rehearsal requires a fair amount of the operator's mental capacity. Other processing interferes with it and it interferes with the processing and storing of additional items (Loftus, 1979). However, rehearsal, by recycling the number of items in STM, allows the operator to memorize long lists surpassing the memory limitations suggested by Miller. Unfortunately, this severely limits the amount of processing capacity which can be directed to other tasks in a complex environment. Thus, simple storage and call up capabilities in a decision-aiding system could significantly reduce operator workload.

Long Term Memory

Whenever a fair amount of rehearsal or processing takes place, some of the items in STM are stored permanently in long term memory (LTM). LTM is not simply a passive storage system, but is also a set of rules and networks of directed relationships used to retrieve items from passive store to active memory (Norman, 1968, 1973). Thus, LTM is represented by two boxes in Figure 2, a retrieval rule system and a passive store system. The retrieval system consists of semantical and syntactical rules, directed graphs and a register of important addresses (Norman, 1973). Recently acquired and important items can be looked up directly because their address is currently stored. However, most items in LTM do not have stored addresses and must be searched for in passive store. Retrieval rules and possible associations allow for efficient search somewhat like searching for a book in a library (Norman 1969). That is, only a small subsection of the possible books in the library need be searched. For example, if only the first initial of the author's last name and the general subject is known, someone familiar with the library's filing system can limit the number of books that must be checked to a small subset even in a fairly large library.

LTM is both more and less efficient than storage systems in computers. Compared to computers, its storage capacity is immense but unstable. Even the retrieval of a list seen the day before may not be possible for the human memory system, but is trivial for a small computer. On the other hand, human memory can see patterns of remote associations which would be impossible to program on a computer. An efficient decision-aid should use the strengths of both human and computer memory systems! The next section is a survey of experimental results from the human memory literature.

LITERATURE SURVEY

Visual Sensory Register

Sperling (1960) demonstrated the existence of a visual sensory register using a partial report experimental paradigm. For very brief presentations of visual stimuli, it was noted that humans could only report about four items. Sperling showed that this had to do with the report process and not the storage process. He used arrays of up to 16 items and then randomly cued a particular row of the display a half-second or so after the array was no longer on the tachistoscope. The subjects could report most of the letters for a particular row indicating they stored the whole array. Thus, there seemed to be some sort of sensory register which briefly stored visual information to be selectively processed and subsequently stored in STM.

Acoustic Encoder

Conrad (1964) found convincing evidence that verbal items stored in STM are acoustically coded. Slides of letters were visually presented to telephone

operator trainees. After six letters were presented, the trainees wrote them down. A confusion matrix indicated that the mistakes could be accounted for by acoustic confusions (B for V) and not physical confusions (T for F). The same pattern of confusions was evident when Post Office employees had to write down auditorially presented letters in white noise, suggesting both sets of stimuli were coded acoustically in STM (see also Conrad, Freeman and Hull, 1965).

Another important study showed the relationship between acoustic encoding and visual sensory register (Posner, Boies, Eichelman and Taylor, 1969). The subjects had to respond to letters that were physically identical or physically dissimilar but with the same name (e.g., a capital A followed by a small a). For both conditions, subjects responded "same" to letters with the same name, and responded "different" otherwise. When the letters were physically identical no acoustic encoding was necessary. The superior performance for the identical condition indicated that acoustic encoding interferred with processing of subsequent stimuli.

Some of their other results suggested that items could be physically stored as visual images more than the half-second or so found by Sperling (1961). However, prolonged visual storage was inefficient if concurrent mental activity was going on. Still other results indicated that presenting an auditory stimulus as a second stimulus resulted in faster recognition performance. The auditory channel appears to offer the possibility of bypassing or easing the acoustic encoding requirement and thus reducing the processing load (see Figure 1).

Using the auditory channel to present critical stimulus information is strongly suggested by these results. Better yet, the use of both visual and auditory channels to present redundant information in critical and stressful situations would be efficient for two reasons: (1) other research has shown the use of redundant stimuli facilities storage in STM (Baddeley, 1964) and, (2) stimulating separate sensory channels will result in minimal processing and storage interference.

STM

For situations where STM includes a rehearsal loop and symbols must be stored for more than a few seconds, named symbols are stored more efficiently than random geometric shapes (Loftus, 1973). Loftus had subjects memorize strings of 16 letters (named) and 16 random geometric forms (unnamed-random). There were both qualitative and quantitative differences in the way they were memorized. Letters showed a serial position enhancement. The first few and last few items were remembered better than the middle letters in the series. It was hypothesized that encoding the name of the first few letters was done without interference, and that the storage requirements of the last few items were minimal, making the middle items in the series the most difficult to remember.

Geometric forms showed no serial-position effect. Storage of named items was more efficient than storage of geometric forms. This suggests that, in the first few seconds, acoustic rehearsal is more efficient than non-acoustic rehearsal.

Sanders and Moss (1973) investigated the effects of introducing additional items both visually and orally during rehearsal. The input channel used did not affect performance. However, having the subjects vocalize during the rehearsal process greatly impaired memory performance. This agrees with literature in other areas of human performance which suggest that output (i.e., response) processes overload the human's processing capacity to a much greater extent than do input (i.e., perceptual) processes. (Alluisi, Muller and Fitts, 1955; Teichner and Krebs, 1972).

The storage of non-verbally encoded items in STM is not as fully understood as verbal storage. Lehito and Kauri (1973) presented parts of a picture previously memorized as a whole picture to their subjects. The subjects had to recognize whether any one of the six parts of the pictures visually presented to them was not in the original picture. Reaction time depended on how far apart the segments of the presented pictures were from each other in the original picture. Apparently, a visual image of the picture was stored in memory and it was scanned much the same way it would be scanned if the actual picture were in front of the subject.

Spatial Memory

However, more recent research suggested that the process was not as simple as initial results indicated. Lehtio, Poikonen and Tuunianen (1980) had their subjects locate relative locations of streets from memory. The task was to decide from memory whether a city street was to the right or left of familiar location. The responses were fastest when streets were furthest away from the known location. If their subjects were mentally scanning a map, the results should have been the opposite. Lehtio,et al (1980) concluded that besides mental maps of various locations, their subjects had a general "spatial schema" which they used for decision-making. Thus, when something was obviously to the right or left of a known location, they responded quickly. It was only when the location was close to the known location, that it was necessary to scan a "mental map" in order to decide relative locations.

This concept of a mental map is very similar to what Baddeley and Lieberman (1980) refer to as "spatial working memory." Apparently, spatial relationships have some isomorphic representation in STM. That is, the human is able to remember general physical "schemas" of objects in space. Furthermore, "spatial memory" is necessary to perform certain tasks.

For example, mnemonic devices have been used as memory aids for a long time (Norman, 1971). One particular mnemonic device consists of a "walk around the campus." The person remembers by mentally picturing himself walking around a

familiar campus and associating a word with each building. Baddeley and Lieberman (1980) found this "mnemonic" improved memory performance in relation to a control group which used rote memory to remember a word list. However, if they were performing a pursuit tracking task during recall, the performance for the "mnemomic" group was degraded whereas the "rote memory" group was not affected by the tracking task. The explanation was that the "mnenomic" device involved "spatial working memory" which also affected the pursuit tracking task because both tasks required subjects to use spatial concepts. Baddeley and Lieberman (1980) presented other evidence that some memory tasks interacted with current task demands in a selective manner.

The design implications of a "spatial working memory" are important. Humans appear good at remembering and using general spatial "schemas" and imagery. However, when they are overloaded, their ability to use these memory components is degraded (Baddeley and Lieberman, 1980). Thus, the ability to selectively call up pictorial maps or representations would be particularly useful when the human operator is performing difficult tracking tasks such as flying an airplane. The important point to remember is that task loading may not be additive. Two tasks which are moderately difficult but involve different memory components (e.g., rote verbal memory and tracking) may be performed concurrently with little difficulty. However, two other moderately difficult but interactive tasks (e.g., tracking and remembering locations on a map) could overload the operator under similar circumstances.

LTM and Semantic Memory

Traditional studies of long-term memory involved memorizing lists or pairs of words and measuring the effects of both intervening activities and time (Kling and Riggs, 1972). The general finding was that specific events interferred with retrieving items from LTM. Deleterious effects on new items due to previous learning are known as proactive inhibitions; performance degradations on past learning caused by learning a new set of relationships are known as retroactive inhibitions (Kling and Riggs, 1972). The design implication of this research is that humans are poor at remembering lists verbatim for any length of time particularly when intervening activity prevents rehearsal. For this reason, long lists which are important to the operator's mission should be stored in computer memory and called up and displayed only when the list is needed.

Obviously, the dynamics of human LTM involves much more than memorizing lists. List memorizing research tends to neglect the importance of general knowledge. People are continually retrieving bits of past knowledge in order to give context to data currently being processed. Recently, researchers have begun studying the effects of general knowledge on current processing tasks subsumed under the name "semantic" memory. This research studies the effects on retrieval time of items with varying semantic relationships (Kintsch, 1980).

For example, Schrandvedelt and Meyer (1973) had subjects say whether a three item group of word-like stimuli contained all words or not. When two of the words in a string were semantically related (bread, butter) retrieval time was faster than for semantically unrelated words. This suggests that words like bread and butter have similar retrieval rules facilitating their recall when they are used together. Also, context plays an important part in verifying the truth or falsity of sentences. For example, "A robin is a car" is responded to as false significantly faster than the sentence "The robin is a mammal." (Kintsch, 1980). (Presumably because a robin is more like a mammal than a car.) There is a growing body of research that indicates that retrieval from LTM depends on the semantic structure of the data being processed (see also Jones, 1980). However, Kintsch points out that beyond recognizing that the human's general knowledge affects LTM retrieval, there is not a model which really can explain the dynamics of this relationship. Even without a general model of the effects of past knowledge on memory retrieval processes, the literature suggests a common sense guideline for control/display design. That is, the word or symbol chosen for different response buttons should be as semantically unlike as possible to avoid confusions.

DISPLAY GUIDELINES

A display is both an extension of the operator's active memory and a means of presenting information to the operator. The use of certain procedures and symbols can improve the operator's storage capacity. If the display demands too much processing by the operator, his capacity to make timely decisions could be overloaded. The following principles were derived from the research on human memory. Using these principles of display design will help insure that the displayed information does not overwhelm the operator's memory.

1. <u>Presentation Rate</u>.

a. The information presentation rate should not force the operator to exceed his STM span (usually about seven items at once in active memory (Miller, 1956)).

b. When information must be updated quickly, the most important information should be cued to insure that these items are the first to be processed off the sensory register (Sperling, 1961).

2. <u>Symbol Principles</u>.

a. Display symbols which are likely to be stored together in STM, should be chosen so they are <u>not</u> acoustically confusable (Conrad, 1964).

b. When the operator is performing a visual processing task, auditory signals can be used efficiently to note important changes, especially if they are redundant with a concurrent visual symbol (Posner, et al, 1969).

c. Symbols with names are more efficiently stored in STM than are random geometric symbols (Loftus, 1979).

d. Aids relating to spatial representations should be particularly helpful during overload situations for tracking tasks (Baddeley and Lieberman, 1980).

3. Capacity Principles.

a. Redundant stimulus information will increase STM capacity (Baddeley, 1964).

b. Chunking items into codes increases storage capacity (Miller, 1956).

c. Rehearsal procedures can increase the number of items stored in memory, however, these procedures interfere with any other processing that must be done (Posner, 1967).

d. If a list might exceed capacity, the first and last few items on the list should be the most important items (Loftus, 1979).

e. Tasks which occupy the same memory domain such as spatial memory can interact with each other to cause overloading (Baddeley and Lieberman, 1980).

4. LTM Principles.

a. Lists which are long and detailed should be passively stored in the computer until called up by the operator (Kling and Riggs, 1974).

b. Symbols which must be used for different responses should not be semantically similar.

HUMAN PROCESSING SYSTEMS

GENERAL DESCRIPTION

Human information processing refers to transformation of sensory data into information in order to accomplish some cognitive task (reading, classification, etc.). The remainder of the paper will discuss various processing models and how they relate to the following processing tasks:

1. Recognition of simple symbols.
2. Higher level recognition.
3. Classification tasks.
4. Search tasks.

Before discussing these specific tasks, an overview of human processing is provided. Memory and processing are interrelated. The following discussion will show to what extent processing and memory systems interact.

It is helpful to think in terms of a central processor (analogous to a CPU in a computer). A central processor coordinates all the processing and memory subfunctions necessary to accomplish a particular task. For example, recognizing a letter entails stimulus encoding, storage in STM, retrieval of information from LTM, etc. The central processor coordinates and directs these activities.

Figure 2 shows both the actions of the processor on various subsystems (A) and the effects of these subsystems (B) on the processor. Starting at the left-hand side of Figure 2, the first arrow indicates that the processor is continually monitoring incoming sensory data on the register (1). This is referred to as "preprocessing" (Niesser, 1967). Monitoring is necessary to note important environmental changes which might otherwise be ignored (Sokolov, 1973).

A good example is the "cocktail party phenomena." At a cocktail party, although a number of conversations are taking place in close quarters simultaneously, participants can pay attention to their own conversations and completely ignore other conversations. However, if one's name is casually mentioned in another conversation, one is often able to shift attention immediately to this conversation. Since only one conversation is being attended to consciously, it is clear that the information from the other conversation must be being monitored at a pre-conscious level (Broadbent, 1971, Norman 1969).

The next arrow in Figure 2 denotes the scanner/encoder mechanism. This mechanism performs a "gating" or "filtering" function (Broadbent, 1971). The processor directs the scanner to sample certain types of information (e.g., female voice) from the sensory register and ignore other types of data. If the processor was not selective in what information to sample, processing capacity would be overloaded for even the simplest task. The processor decides what data sources are pertinent for a particular task and directs the scanner to sample only

these sources (Norman, 1968). However, the preprocessing mechanism alluded to previously can override this directive in the event of important environmental changes.

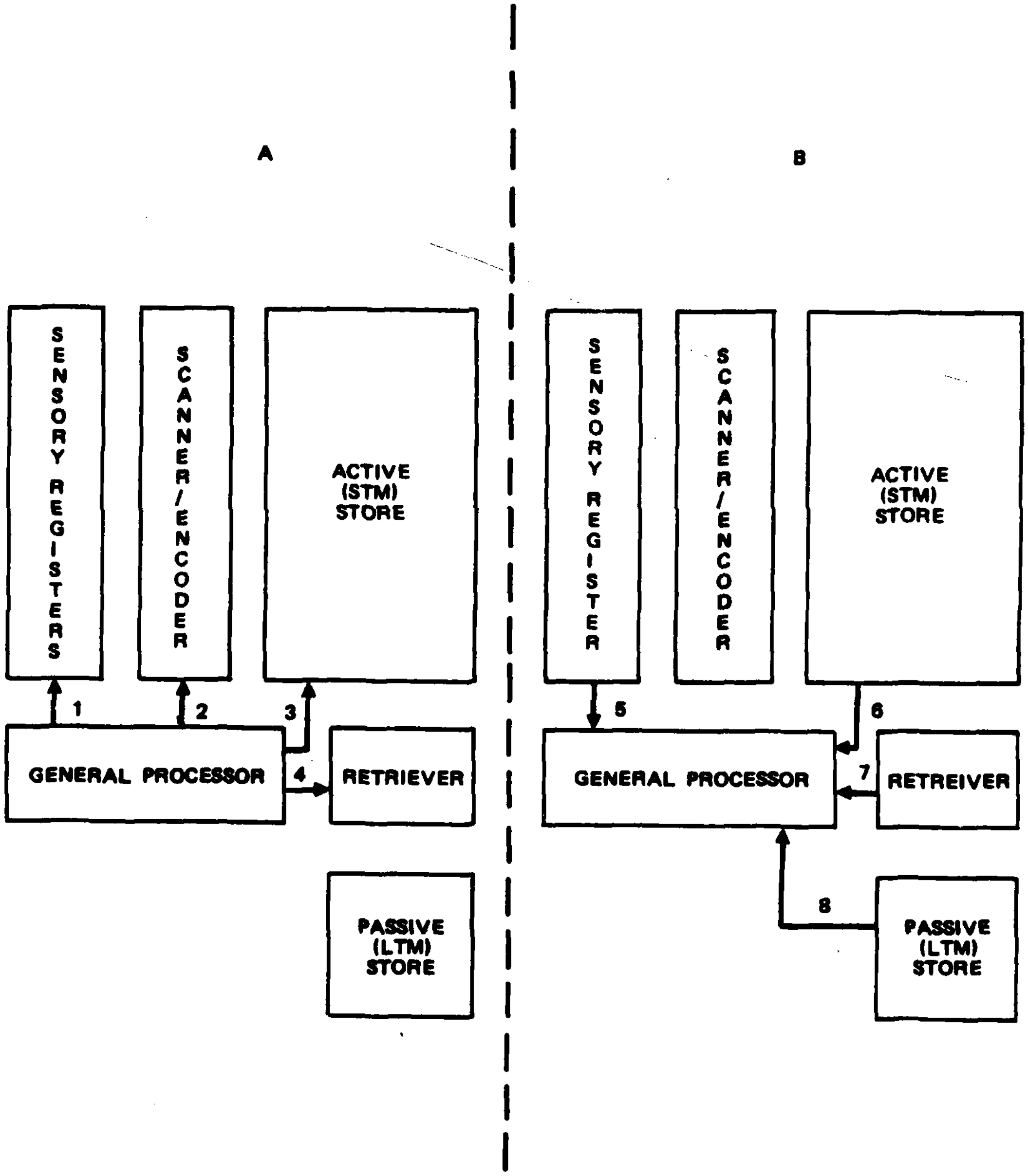

FIGURE 2. The Relationship Among the Central Processor and Various Memory and Processing Subsystems.

Active or STM memory is the residence of conscious analytical tasks such as reading or problem solving. The central processor operates on symbols in STM, classifying them and logically manipulating them as necessary for problem solving (Posner and Klien, 1973; Newell and Simon, 1972). It should be noted that certain cognitive tasks become automatic with repetition and are done without conscious awareness (Kelley, 1968). As the fourth arrow indicates, the processor keeps the retriever primed for querying certain types of information from LTM. The retrieval rules depend on current task requirements and are geared to make memory retrieval efficient for that task.

The other side of the coin is that all these systems effect the central processor. Unanticipated events noted on the sensory register can cause the processor to change its operating mode (5). Sokolov (1963) argues that there is an Orienting Reflex (OR) which causes the processor to automatically redirect the focus of attention when sensory inputs signal important environmental changes.

The other memory systems have important effects on the processor (6, 7, 8). The information stored in STM (6) provides the immediate context to interpret sensory data. A word may have several definitions stored in LTM, but the correct meaning is usually accessed readily because of the context in which the word was processed. Also, the rule retrieval system (7) can cue the processor as to what words to anticipate in a conversation because of the logical structure of language rules.

One of the most important items stored in LTM is a "script" (8). A "script" contains guidelines as to what information and actions are pertinent for a particular activity (Kintsch, 1980). A "script" allows humans to consider information concerning an event prior to its occurrence. For example, training allows pilots to have a "script" for emergency situations, preparing him to process pertinent information quickly and efficiently. In summary, processing involves a complex interaction of memory and processing subsystems. The central processor coordinates these subfunctions in order to perform various cognitive tasks.

The next section discusses a general model of feature extraction. This model describes how symbols are encoded and it is necessary to explain this model in detail in order to understand the subsequent discussions of the various processing tasks. Each of these processing tasks (i.e., symbol recognition, higher level recognition, classification and search) will be discussed in subsequent sections.

A FEATURE EXTRACTION CODING MODEL

The manner in which we recognize visual stimuli is based on the neuron code projected to the visual cortex. Electrical measurements taken on the visual cortex and lateral geniculate body indicate a functional relationship between nerve firing rates in specific locations and stimuli impinging on the retina (Hubel, 1963). Simple cells in the cortex respond to light energy and size,

whereas more complex cells will respond to stimuli in specific orientations. For example, cells in the striate cortex of cats have been found which respond to a horizontal stimulus and will stop responding with a 5 to 10° shift in the stimulus' orientation (Hubel, 1963). Complex cells receive their inputs from a larger number of simple cells and presumably feed into an even smaller number of more complex cells. As complexity increases, the features to which the cells respond become more specific. In terms of processing models, this means that the processor most likely uses simple codes to extract features from symbols in order to recognize them.

Figure 3 represents a general model of symbol recognition based on feature extraction. This pattern recognition process involves simple codes similar to those available in the human nervous system (i.e., excitatory +, inhibatory -, or steady state 0). As an example of how these codes are used, the symbol "2" is initially analyzed using a very simple coding scheme. It is assumed that equally spaced detectors analyze the curve pattern: for convex curves the detector uses a -, for concave curves the detector uses a +, and for straight lines the code is 0. Next, a higher order feature coder examines the simple code and uses this information to generate a more complex code to form a Feature File. For example, the complex coder codes file 1 (f_1) as + to denote that the top half of the letter is a concave curve. The 0 in f_2 denotes that the letter is basically straight on the bottom half and f_3 might indicate whether there is more curved than straight surface area on the letter and so on for each of the files ($f_1 \ldots f_i \ldots f_{10}$).

Thus, by starting with a fairly simple code a feature file can be built up. In Figure 3, the feature file is shown as channel 1. In order to recognize the symbol "2," channel 1 is compared to a master file in LTM and the patterns of +, -, and 0 for each slot would match with a digit named "two." There are only ten slots for the file. However, there are over 1,000 possible patterns using a +, -, 0 code with ten slots, suggesting that the human can differentiate among a large number of items using a relatively small set of features.

Another aspect of the model is that there is more than one channel available to be used for feature files at the same time. Thus, a group of letters can be coded simultaneously as long as their number does not exceed the number of channels available. This aspect of the model is referred to as parallel processing of features.

RECOGNITION OF SIMPLE SYMBOLS

This general model of feature extraction is intended to represent various aspects of models of symbol recognition generated by Estes, 1972; Gardner, 1973; Morton, 1969 and Rumelhart, 1970. The main point of contention among these models is whether the parallel channels are analyzed with "unlimited" capacity or not. By "unlimited" capacity it is meant that the number of items which must be processed simultaneously does not affect processing rates for individual items (i.e., eight items processed as quickly and accurately as one

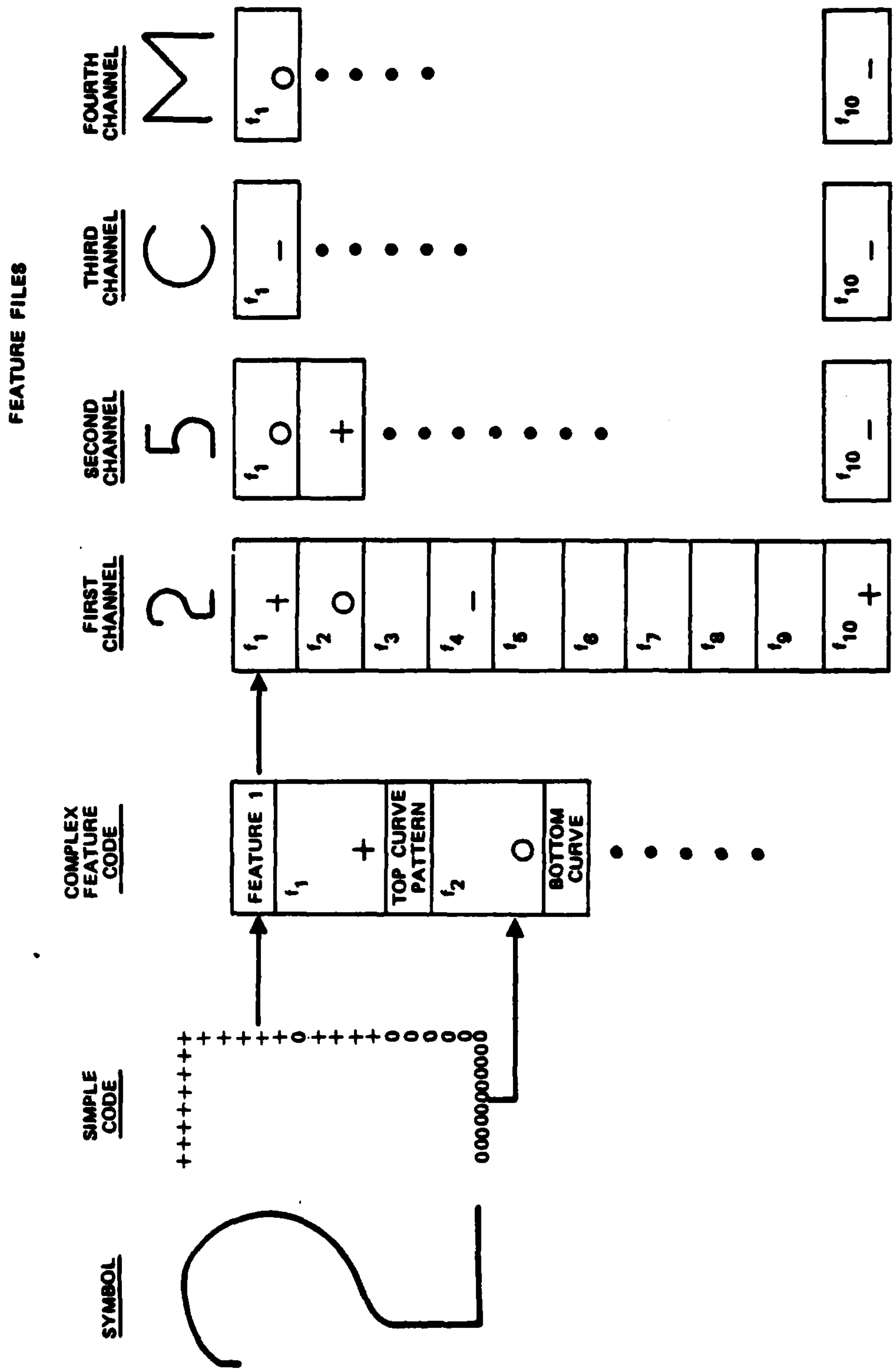

FIGURE 3. A General Model of Feature Extraction For Symbol Encoding.

item). A limited capacity model, on the other hand, implies that capacity is split among channels (Atkinson, Holmgren and Joula, 1969; Townsend, 1974). The limited capacity model (Rumelhart, 1970) was derived to explain the fact that processing time increases as the number of display items increases. However, this seems to be only so when the display items are physically confusable (Estes, 1972). Gardner (1973) argues that the extra processing time for additional display items is a function of their confusability. In terms of the feature file, this is apparently because more slots ($f_1 \ldots f_i \ldots f_n$) must be examined whenever confusions are possible among the channels.

All of the experiments reviewed here had a similar design. Subjects decided whether a letter was present or absent from a display. Figure 4 shows the type of displays used in the experiments. The main question motivating these research paradigms was how well humans could recognize target elements when the number of non-target elements increased. Usually half of the trials had a target letter embedded among the non-targets and half contained only non-target letters. As the number of display elements increased, (from one to up to 16 items) reaction time increased (Atkinson, Joula and Holmgren 1969; Estes and Wessel, 1966) and/or proportion correct decreased (Estes, 1972; Gardner, 1973; Eriksen and Spenser, 1969).

Ericksen and Spenser (1969) had their subjects say whether a target was present or not. The letters on the circular display (see III, Figure 4) were presented in sequence and the subjects responded after all letters had been displayed. The interstimulus interval (ISI) was varied from 5 to 30 msec with the target being the first, middle and last item displayed equally often. The experimenters found that neither the position of the target nor the rate of presentation affected performance. If display processing was serial (i.e., processing of one item at a time), the time the target was presented would have effected performance since the processor had to examine all previous items before it processed the target. However, performance was equal regardless of whether the target was the first or last item presented. This suggests that processing began on the target as soon as it was presented and while other items were still being processed. Thus processing seemed to be in parallel, but performance decreased as a function of the number of display elements, suggesting a limited capacity system.*

Gardner (1973) and Estes (1972) showed that this performance decrement washed out if the non-target items in the display were not confusable with the target item. Gardner argued that performance depended not on the number of channels which must be examined, but only on the possible confusability among the channels. Looking at Figure 4, it should be obvious that if the symbols are radically different, coding the slots for one or two features should be sufficient

*These results could have been predicted from other processing models (Townsend, 1974). However, the ability of humans to process larger units such as words (see next section) makes parallel processing of contiguous items the most plausible explanation.

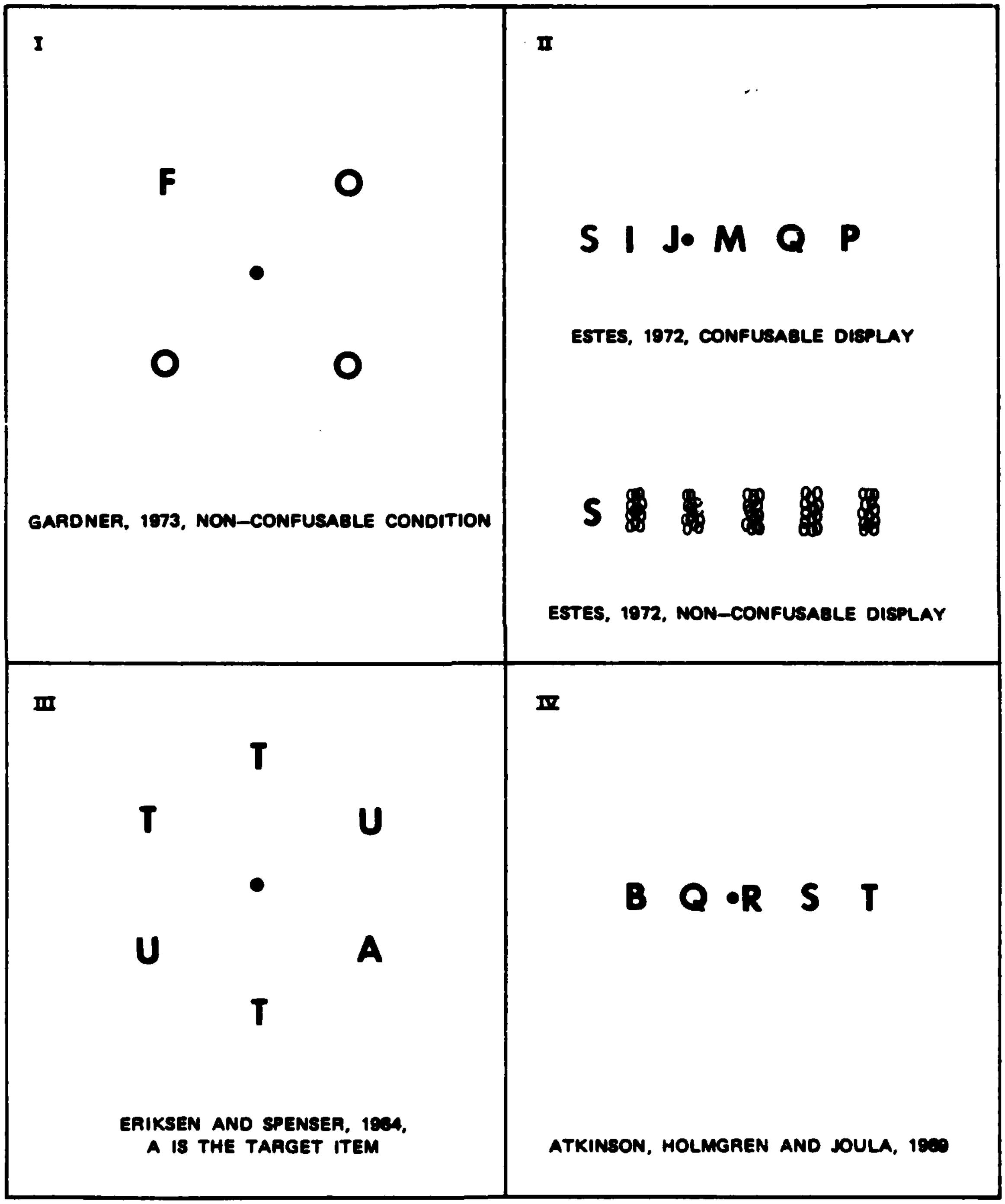

FIGURE 4. Displays Used For Symbol Recognition Research.

to differentiate among them. However, if they are confusable, the number of features which must be coded increases. For example, in Gardner's non-confusable display, any item with a + or - in either curve feature slot (i.e., f_1 or f_2) in Figure 1 could be dismissed because the target letter has no curves. Thus, the differentation task becomes fairly easy.

Eriksen and Spencer (1969) found that the hit rate (proportion of correct "yes" responses when the target was present) was not affected by the number of confusable non-target elements, although the false alarm rate increased (proportion of "yes" responses made to non-targets).

Now, if the system had unlimited capacity, hit rate should increase proportionately with false alarm rate. Equation (1) indicates that hit rate depends on saying "yes" to a target when it is present, or saying "yes" to non-targets when the target is actually present minus the probability of both events occurring.

$$P(H) = P(Y \mid T) + P(Y \mid \overline{T}) - P(Y \mid T)\, P(Y \mid \overline{T}) \qquad (1)$$

$P(H)$ = probability of hit when target is present.
$P(Y \mid T)$ = probability of saying yes to a target.
$P(Y \mid \overline{T})$ = probability of saying yes to a non-target.

An "unlimited capacity" model predicts that $P(Y \mid T)$ should not be affected by the number of channels, so if false alarms increase (i.e., $P(Y \mid \overline{T})$ this model necessarily predicts an increase in hit rate. Since this was not the case for Eriksen and Spencer's data, there was something besides confusability affecting processing rate as the number of non-target elements increased.

Estes (1972) suggests there are two response processes evident in symbol recognition. In one case (called primary responses), the target symbol stands out and is obvious. For the other responses (secondary) processing takes longer and, in his experiments, is more error prone. This "two process" strategy crops up in many human performance tasks (Broadbent, 1971; Egeth, Jonides and Wall, 1972; Neisser, 1967; Posner, Boies, Eichelman and Taylor, 1969) and seems to be a general feature of human processing.

The description of primary responses suggests a "gating" mechanism. The processor gates (i.e., ignores) "non-target" items and does extensive processing only on items which are potential targets. When display elements are nonconfusable, processing would be similar to a one item display since only one item could possibly be the target. However, for confusable displays, there are a number of candidate targets and each would have to be compared with the master file LTM resulting in longer, more error prone processing (Rumelhart, 1970).

Estes (1972) and Gardner (1973) also pointed out that display element placement affected recognition. Adjacent items in linear displays could each mask the other's contours due to lateral inhibitions by the visual receptors. Also, items nearer the fixation point were resolved foveally in the retina resulting in

better recognition, especially when other display items were confusable. In summary, symbol recognition in multi-element displays depended on the physical and spatial characteristics of the display elements. Whenever these elements were nonconfusable, a simple "gating" mechanism results in quick, accurate processing, independent of the number of display items.

Display Guidelines

The most important principle to be derived from the literature involves the relationship between confusability and display elements. For an array in close physical proximity (i.e., it can be processed in one eye fixation), processing nonconfusable symbols will not interfere with recognizing a target item. Thus, theoretically, arrays can be designed to impart large amounts of information without the individual symbols interfering with the processing of a target item. In practice, however, this possibility is very limited because it would be difficult to find any set of simple symbols with more than a few items which are not physically confusable. It does suggest that codes relating to two different sources of information could be used together in the same array without interfering with each other. This is possible if their symbols were physically dissimilar (+ and 0, for example). Theoretically, the processor could gate the code not relevant for current task demands. Other principles involve how items are displayed in relation to one another:

1. Adjacent items will mask each other, if they are placed too close together.

2. For updating important information, redundant symbols will increase detection probabilities.

3. Information in the center of display, where the operator is more likely to be looking, will be detected more rapidly.

HIGHER-LEVEL RECOGNITION PROCESSES

Verbal Units

The previous discussion involved simple symbols such as letters or geometric forms. This section involves higher level combinations of symbols including words, sentences and patterns. The issue this section addresses is whether higher-level recognition is fundamentally different from simple recognition or is it simply a question of processing more information. Smith and Spoehr (1974) argue that for word recognition, two distinct processes are involved. The letters are recognized in much the same way as outlined in the previous section. However, words and word-like strings are recognized in a more holostic, almost gestalt manner. That is, recognition performance depends on the orthographic context of the word string and not simply on the number of

letters which much be recognized. As a matter of fact, recognition is usually better for single letters if they are embedded in a word than if they are presented alone (Reicher, 1964; Wheeler, 1970; Massaro, 1980; Kreuger and Shapiro, 1980; Herstenson, 1972).

That the string of letters is a word does not seem to be as important as that it is pronounceable and follows English spelling rules. Orthography is the general study of words in terms of their spelling structure and pronounceability. The English language follows certain rules in converting spelling of letters to pronounceable entities. For example, vowels are pronounced differently depending on the spelling of the word. The rules tend to be fairly complex, but orderly (Venezky, 1967). A good speller can correctly spell words which he has never heard before based on their pronunciation. The point here, is that single letters sound quite a bit different depending on their orthographic context. Also, letters are not usually seen in isolation. Thus it is not surprising that the human perceptual system might take advantage of such rules and as a result be more efficient at processing larger, more informative units than at processing single letters. The processing of words and orthographic units becomes an automatic process for most literate adults (Laberge and Samuels, 1974). However, letters, because they either influence how other letters sound or are influenced by other letters in the same way, are usually processed as part of a larger analytical unit. Processing them in isolation seems to be a relatively more difficult and less automatic process.

Experimental evidence indicates that visual perception and extraction of letter information from the sensory register is <u>not</u> affected by whether the target letter is isolated or in a word (Hershenson, 1972; Krueger and Shapiro, 1980; Massan, 1980). The advantage of a letter being embedded in a larger unit, apparently involves later processing stages. All the letters in an orthographic unit are probably stored at a single location in LTM containing a subroutine. The subroutine generates the motor program necessary to produce the sounds associated with the unit (Lieberman, Cooper, Shankweiler and Studdert-Kennedy, 1967).

The reason that units that follow orthographic rules are processed so efficiently most likely involves initial encoding and retrieval from LTM. The feature extraction model (Figure 3) posits that letters are processed in parallel. Thus information about individual letters and also the complete unit are available simultaneously. In the case of words and orthographic units, partial information concerning a number of letters is particularly valuable because the letters are highly correlated. For example, for a three letter orthographic unit, knowing that the second letter is probably an i and that the third letter has a number of alternating curves reduces the number of possible units to a fairly small subset. This is because, statistically, there are not many three-letter units with both these constraints that also follow orthographic rules. The advantage of units with statistical constraints is that the processor can simultaneously use the physical features of individual parts and the statistical constraints of the unit as a whole to correctly encode incoming sensory data (Massaro, 1979).

The notion that units have global features which are unique to a unit seems to be the basis of much of the earlier work done by Gestalt psychologist. The strategy of looking at global features rather then analyzing parts of a unit involves what has been referred to as a unitization strategy. (See also Cooper, 1980, Palmer, 1977.) The research on word recognition suggests that the processor uses both a unitization strategy and a feature extraction strategy when encoding high-order units (Massaro, 1979).

Morton (1969) extends this general notion by suggesting that word recognition is influenced by the context of the word. Sentence structure and semantical context limit what a word could be in most real life, non-laboratory, situations. The last word of a sentence is sometimes quite predictable by the context which preceded it. This suggests the basic unit of perceptual analysis might be fairly large. Smaller units such as orthographic units and words can be lumped together into larger units such as word phrases or even short sentences to form primary units of analysis. Furthermore, this implies that the redundancy evident in the English language is efficient since it improves recognition performance for smaller sub-units such as letters, words, etc.

Non-Verbal Higher-Level Recognition Processes

Cooper (1980) points out that the processor is able to use global features of a unit efficiently for many types of processing tasks besides those dealing with verbal stimuli. It has been recognized for a long time that humans are very good at pattern recognition. What is not well understood is why certain patterns are more easily recognized than others. Historically, certain Gestalt principles such as enclosure, figural goodness, etc. have been established. However, quantitative analysis of patterns or complex structures using procedures such as information metric have had mixed results (Coombs, Dawes and Tversky, 1971).

More recently Garner (1974) has analyzed such principles as figural goodness and attempted to quantify them. Garner believes that humans judge patterns in terms of a perceived set of possible alternative patterns. So-called good patterns, Garner argues, are those that are seen as belonging to a small set of possible configurations (i.e., there is little uncertainty involved). He measures uncertainty by rotating patterns on their axis. "Good" patterns maintain the same configuration throughout the various rotations. "Poor" patterns change configurations with every rotation. The advantage to this procedure is that patterns can be scaled, and the resulting scales have been found to correlate with various behavioral measures.

Garner also has attempted to quantify the perception of multidimensional structures and has found that dimensions may be integral or separable. That is, two physical dimensions such as color and brightness may be perceived as a single combined integral dimension psychologically or seen as two distinct dimensions (i.e., separable).

Garner measured integrality using multidimensional scaling techniques. Subjects make similarity judgments concerning different stimuli. A dissimilarity scale was generated as a function of the dissimilarity (d) of the dimensions using two dimensions X and Y. If the scale was best fitted by a Euclidian function ($d_{xy} = (d_x^2 + d_y^2)^{1/2}$), the dimensions were considered to be integral. An additive function ($d_{xy} = d_x + d_y$) indicated separable (independent) dimensions. Garner validated these scales by making predictions concerning a number of converging human performance tasks with integral and separable multidimensional stimuli. Actual performance seemed to validate the metric.

A number of very recent findings at the University of Michigan's Human Performance Center leave considerable doubt as to whether integral dimensions are a necessary result of Euclidean functions or that the tasks Garner developed are always good predictors of integrality (Cheng, 1980; Somers, 1978). Still this general approach to measuring psychological rather than physical dimensions of multidimensional structures should prove to be very valuable for display technology. Such scales are needed to measure the effects of scene complexity, complex symbols and realistic scenarios. Such a metric would allow the designer to make trade-offs between display parameters and human performance during the design process. Presently, such variables are usually measured after the displays have been designed.

Summary and Display Implications

Figure 5 summarizes the relationship between simple and complex (i.e., higher-order recognition) processes.

Simple symbols are recognized by the processor generating feature lists in order to find the proper code in LTM. A gating mechanism allows the relatively quick elimination of symbols which are visually unlike the target symbol. However, when the recognition task involves recognizing a target in a crowded display, gating is only possible for physically non-confusable stimuli. If the non-target symbols are similar to the target, a comparison of each of the item's coded features with a master file in LTM is necessary.

The processing of higher-order units is not simply the sum of the processing of its parts. By using a unitization strategy, the processor focuses on the properties of the entire unit rather than serially processing each of its constituent parts. This allows the processor to take advantage of the statistical constraints present in certain units, since the acoustic encoding of verbal material is often ambiguous for many small units such as letters without the context provided by larger units. Multidimensional stimuli are processed in terms of separate independent dimensions or the processor may perceive two or more dimensions as psychologically integral.

The main point to be gleaned from this discussion is the advantage of using context and the natural redundancy of the English language when presenting information. The engineering solution to symbol display is to display the

maximum amount of information with the fewest symbols. That is why single alpha-numerics, abbreviations and other simple codes are utilized to convey information. In some cases, this may be necessary because of equipment limitations. However, the performance gains from using words or even sentences instead of single symbols should be considered during the design process. Important functions (such as emergency instructions) which may be displayed only rarely, should be conveyed in terms of human efficiency rather than engineering efficiency.

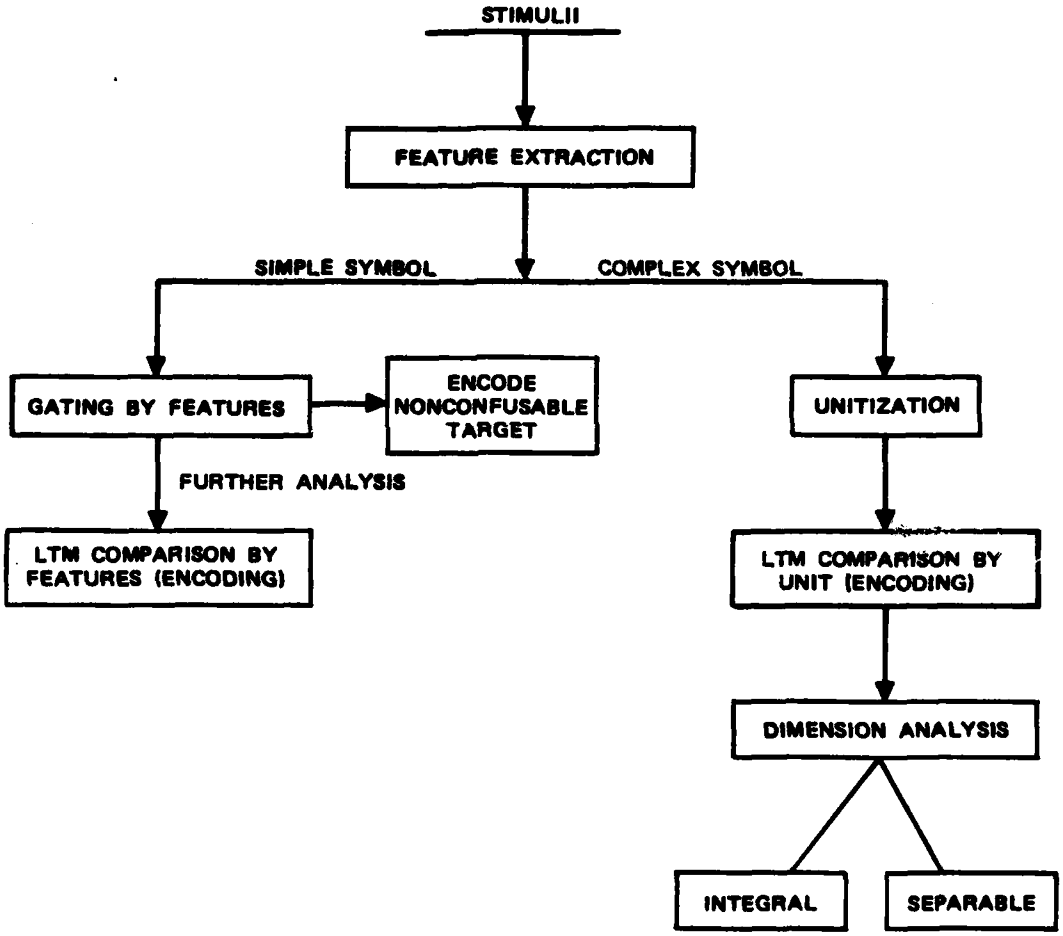

Figure 5. Outline of Simple and Complex Recognition Processes.

STIMULUS CLASSIFICATION (S-S AND S-R EFFECTS)

The previous sections dealt with recognizing and encoding stimuli. This section deals with classification and translation processes for encoded stimuli in active memory. S-S processes are operations where a stimulus is classified as belonging to a particular stimulus class. For example, the letter e might be

classified as a vowel. The most important parameter in this type of research has been the size of the stimulus class. S-R translations involve assigning a response to a classified stimulus. For example, all vowels might require a button push with the left index finger (Teichner, 1975).

Donders (1868-1869) devised a method of measuring stimulus encoding, S-S classification and response selection processes by using various reaction time tasks (Teichner and Krebs, 1974A). Sternberg (1969) refined this methodology by varying mental workload in order to measure various independent processing stages. He found that the S-S classification rate (R) was a linear function of the number of members in the stimulus set (S) representing the positive response (Sternberg, 1966).

$$R = a + b(s) \tag{2}$$

He argued that the processor compared a visual image of the presented stimulus to representations of each member of the positive response class in active memory. The target item was not acoustically encoded for the comparison indicating that not all mental operations deal with acoustically encoded stimuli (Sternberg, 1967). The apparent discrepancy between this and our previous discussion involves the short time frame of the task (less than a half second) and the fact that single letters and digits were used. Smith and Spoehr (1974) point out that humans probably do not encode stimuli in any one way, but adapt a strategy depending on the task. For very short operations which involve little STM capacity, using a visual image of simple stimuli for S-S classifications is probably the preferred strategy. This strategy circumvents the acoustic encoding problem.

Sternberg's (1966) results also contradict an earlier finding by Neisser (1963) which suggested R was unaffected by the size of S. However, again this was most likely due to the processor's strategy. In Neisser's task, a very high error rate was permitted (20%) suggesting the gating mechanism alluded to earlier was being used. Since very few features are used for gating, error rate should increase when the processor elects to use it for fairly difficult tasks. Sanders (1980) points out that completely different functions are found for Equation (2) depending on the experimental paradigm used to measure S-S rates. Thus, the original attempt by Sternberg to measure S-S rate using a particular paradigm is not realizable. The processor will adapt different processing strategies to accomplish different tasks. Adaptability rather than consistency seems to be the hallmark of the human processing system.

This does not mean that it is impossible to predict performance for an S-S task. Although the change in processing strategy may not be a conscious decision, it does seem to be very task specific. Equation (2) is a very good predictor of performance for Sternberg type tasks (Pachella, 1974). Results using other experimental paradigms also reinforce the notion that changes in processing strategy can be predicted by specific changes in task parameters. The following effects have been noted for S-S operations.

Practice Effects. The S-S translation process becomes more efficient as a function of practice. The slope value in Equation (2) decreases as a function of practice (Barnes, 1974). It becomes virtually non-existent with enough practice. However, a million practice trials are necessary for the value to become zero (Teichner and Krebs, 1974). This is not a trivial finding because many skilled tasks such as typing may involve a million trials (i.e., pushing one key would be a trial).

Speed-Accuracy Trade-Off. Fitts (1966) found that when payoff was varied to reward speed as opposed to accuracy, response time decreased while error rate increased. Thus it seems the processor can set its processing rate to maximize either latency or accuracy depending on the task demands. Swanson and Briggs (1969) found that the S-S process was not affected by the speed-accuracy trade-off, but that the stimulus encoding processes were. Errors were presumably caused by the scanner sampling a smaller set of feature codes from the sensory register. However, Pachella (1974) found that by inducing more speed stress, the S-S translation process was also affected (i.e., the slope value in Equation (2) decreased as errors increased).

For extreme speed stress, the S-S translation process drops out altogether (Yellott, 1971; Swensson, 1972). Human subjects randomly "preprogrammed" their responses by guessing on certain trials. Again, the processor adapted a different strategy depending on the parameters of the task. As the payoff favored speed, less S-S classification time resulted in more response errors until under extreme speed stress S-S classifications were eliminated.

P-R-P Effects. Whenever one stimulus follows another closely in time, the processing time required for the second stimulus increases. This is referred to as the P-R-P (Psychological Refractory Period) effect and is due to the limited capacity of the processor. Greenwald (1972) found that most of this effect could be traced to S-R rather than S-S processes. If the translation from stimulus code to response code was natural, the P-R-P effect could be eliminated altogether (Greenwald and Shulman, 1973).

Most traditional experiments investigating human reaction time confounded S-R and S-S tasks. Information load was varied for these tasks by increasing both the S-S and S-R load at the same time (Teichner and Krebs, 1974). However, a fairly early study by Alluisi, Muller and Fitts (1955) indicated that the response type affected performance more than did stimulus information rate. More recently, Teichner and Krebs (1974), reviewing the choice reaction time literature found response processes were more important than stimulus information load for well practiced subjects. For these reaction tasks (key punching, vocal response, etc.), the motor program for the response was simple and overlearned. The important factor was the relationship of the stimulus code to the response code. Many of the informational overload effects disappear or diminish when the S-R codes are compatible (Barnes, 1974; Greenwald, 1972; Rabbitt and Vyas, 1973). Thus if there is a bottle-neck in the information processing network, it would seem to involve S-R more so than S-S operations (Broadbent, 1971) even when the response is as easy as pushing a button.

Display Guidelines

1. There is no universal limit to stimulus presentation rate, the amount of stimulus information that can be classified per unit of time, depends on:

   a. The size of the stimulus class represented by a response.

   b. Number of responses.

   c. Practice or experience level of the operator.

   d. Speed/accuracy set of the operator.

   e. S-R compatibility of the displays and controls.

2. The human processor can adapt to task changes by changing its processing strategy.

3. Since S-R factors are frequently found to be more important than stimulus presentation rate; particular consideration should be given to finding S-R compatible control/display configurations. There is no way to measure S-R compatibility except empirically. However, the following factors influence S-R compatibility (Broadbent, 1971; Greenwald, 1970; Greenwald and Shulman, 1973).

   a. S-R compatible relationships are often formed through familiarity (e.g., to turn a light switch on is up in the United States, down in England).

   b. Close geometric proximity of stimulus and response equipment aids compatibility.

   c. Isomorphic relationships between stimulus and response configurations can result in compatibility.

   d. Cognitive similarity of stimulus code and the required response (e.g., an arrow pointing to the button to be pushed) results in compatible configurations.

SEARCH TASKS

So far we have discussed recognizing an item in a single fixation, higher-order encoding, S-S and S-R translations. This section does not attempt to introduce new concepts, but rather to discuss the complexity involved when the processor must perform all these operations during search tasks. A search task involves a rapid processing of items with both temporal and spatial uncertainty. Display density, size, noise, stimulus information, dimensionality of the stimulus, number of targets, and type of targets are only a few of the variables shown to affect search performance (Erickson, 1966; Mocharnuk, 1978; Metlay, Sokoloff

and Kaplan, 1970; Teichner and Krebs, 1974b; Teichner and Mocharnuk, 1979). The problem becomes complex because searching involves all the variables evident for other processing and it is highly dependent on the characteristics of the display to be searched. Thus, if we ask what the operator does during search, the answer is: everything we discussed so far plus more. Teichner and his colleagues (Mocharnuk, 1978; Teichner and Krebs, 1974b, Teichner and Mocharnuk, 1979) used the information metric to measure the amount of stimulus information which must be processed for efficient search. They assumed that search was accomplished dimension by dimension with a sorting process directing search first to those dimensions with the least number of levels. Equation (3) represents the case with an equal number of stimuli per level (Teichner and Mocharnuk, 1979).

$$H(X) = N \operatorname{Log}_2 L_1 + M_1 \operatorname{Log}_2 L_2 + \ldots + M_{i-1} \operatorname{Log}_2 L_i + \ldots + M_{n-1} \operatorname{Log}_2 L_n \qquad (3)$$

where

$H(X)$ = Total amount of stimulus information

N = Total Number of stimuli on the display

M_{i-1} = Total number of stimuli left to be searched before the ith dimension has been processed

L_i = The number of levels in the ith dimension

n = Total number of dimensions

The efficient searcher initially chooses the dimension with the lowest uncertainty first and keeps reducing M (the number of stimuli which must be processed further) after examining each dimension. The metric has the advantage of considering both the human operator and the display characteristics without introducing the complexity involved in considering all possible parameters involved in processing. The equation becomes more complex when the number of cases per level changes, but is still tractable. The metric has been able to predict search performance fairly well in a number of different situations, but still needs to be generalized and perhaps expanded. Mocharnuk (1978) suggests that such factors as display size, and target set size should be incorporated into Equation (3). The following are results from empirical investigations using the metric (Teichner and Mocharnuk, 1979).

1. Search time starts to increase only after a certain "critical" number of items are on display.

2. Targets with more than one dimension (e.g., color and shape) are searched for more efficiently than unidimensional targets.

3. As H(X) increases, processing time per item decreases until a critical level is reached after which processing rate per item is no longer related to H(X).

The results suggest that search efficiency increases as the informational content of the display increases. This supports our notion of a limited capacity, parallel processing system. The processor examines the dimensions sequentially, but operates on more than one display item at once. Until a critical level, representing system capacity, is reached, processing time per item would decrease because the items are being processed in parallel. Equation (3) also suggests many items could be eliminated through a gating mechanism, since only one dimension should be sufficient to differentiate among most target and non-target items if $L>2$ for the most important sorting dimension.

Display Guidelines

1. Redundant multidimensional target stimuli allow for an efficient search process.

2. A critical amount of information, neither too large or too small, results in optimal search performance.

3. Some measure of stimulus information such as Equation (3) should serve as a guide to the optimal amount of information for a display which neither overburdens or underburdens the operator.

CODING OPERATIONS AND SUMMARY

The purpose of this review has been twofold: (1) to attempt to develop information processing guidelines for improving coding procedures for decision aids and, (2) to pinpoint limitations in human performance in order to facilitate man-machine interactions using decision aids.

In the final analysis, most of the suggested guidelines are qualitative and tentative. The few quantitative relationships suggested (Equations (2) and (3)) are narrowly defined and probably task specific. However, most of the guidelines suggested are the result of empirical evidence from a number of different experimental studies. As such, they are useful and should be considered during display design. These guidelines should help generate a number of candidate display configurations when combined with the ingenuity and experience of the display designer.

Unfortunately, no universally accepted metric has been developed to predict operator cognitive performance for different displays. Candidate displays must still be tested empirically before their relative efficiency can be determined. However, some of the reviewed metrics suggest that human engineering technology is approaching the point where cognitive display characteristics can be measured accurately during the design processes.

A number of important characteristics of the human operator's processing performance were found in the literature. The most important principle is that the human processor is both adaptive and highly interactive. It is impossible to predict performance without considering specific task parameters. The processor can adapt its strategy for particular task demands. The following results summarize the operator's processing characteristics.

1. Active memory is a limited capacity system, but many coding schemes and procedures can be used to increase memory span.

2. Processing can operate on items in parallel, but it is a limited capacity system.[1]

3. Two processing strategies for feature coding were identified.

    a. Gating consists of rejecting nonimportant items for further processing on the basis of only a few features.

    b. Full processing is the comparison of a number of feature files with the master files in LTM.

4. A unitization strategy allows the processor to examine larger analytical units (e.g., orthographic) in order to process smaller sub-units (e.g., letters) thus taking advantage of the context and redundancy in the larger units.

5. Whether items are acoustically or visually encoded in STM depends on the task the operator is performing.

6. Classification tasks can be either or both S-S or S-R tasks. S-R tasks and response processes, in general, can be the most frequent source of information overload in humans.

7. S-R compatible codes decrease the effects of informational overload.

8. Search processing is more efficient as stimulus information increases up to a critical limit. After this limit (capacity for that task), performance either does not change or degrades.

Appendix A

COMPUTERIZED DECISION-AIDING

This section defines a decision aid and discusses the problems associated with interfacing a man with an appropriate decision aid. In order to understand the function of a decision aid, a distinction should be made between decision tasks and processing requirements. The decision tasks are shown at the bottom (B) of Figure A-1. They are discussed in detail elsewhere (Barnes, 1979, 1980). The outputs from each task (i.e., (1) information, (2) probabilities, (3) outcome worth evaluations, and (4) decision rules) are used as the basis for choosing the best option shown as the output.

However, in order to do any of these tasks, a fair amount of higher level processing must be done. Some of these processing requirements are shown at the top (A) of Figure A-1. As the decision task becomes more complex, the processing requirement can easily overload the operator. A decision aid then, can be defined as the computerization of any algorithm or processing technique which helps the operator in a decision task. The purpose of an aid is to take some of the processing or storage burden off the operator (Domas and Peterson, 1967; Kahneman and Tversky, 1972). This does not mean that an aid necessarily makes decisions or replaces the operator for a particular task. It only implies that an aid does some of the processing required for these tasks.

Because machines are better at some tasks, and man is better at others, not all the processing requirements in Figure 1 are equally amenable to aiding. The designations in parentheses under the processing requirements suggest one possible scheme of man/machine allocation. This is described below.

Structuring

Currently, structuring is best performed by a human operator. It requires an overview of the situation in order to generate important structural elements (e.g., options available, possible outcomes . . .) and their relationships. Structuring also involves limiting the scope of a decision problem because of temporal and practical constraints. Computer aids using algorithms based on sensitivity analysis, heuristic search techniques and influence diagrams are being developed as possible structuring aids (Leal and Pearl, 1977; Merkhofer, Robinson, 1979). However, these projects are pushing the state-of-the-art and in most circumstances the structuring part of decision-making is left to experts who plan systems or to the operator during actual operations.

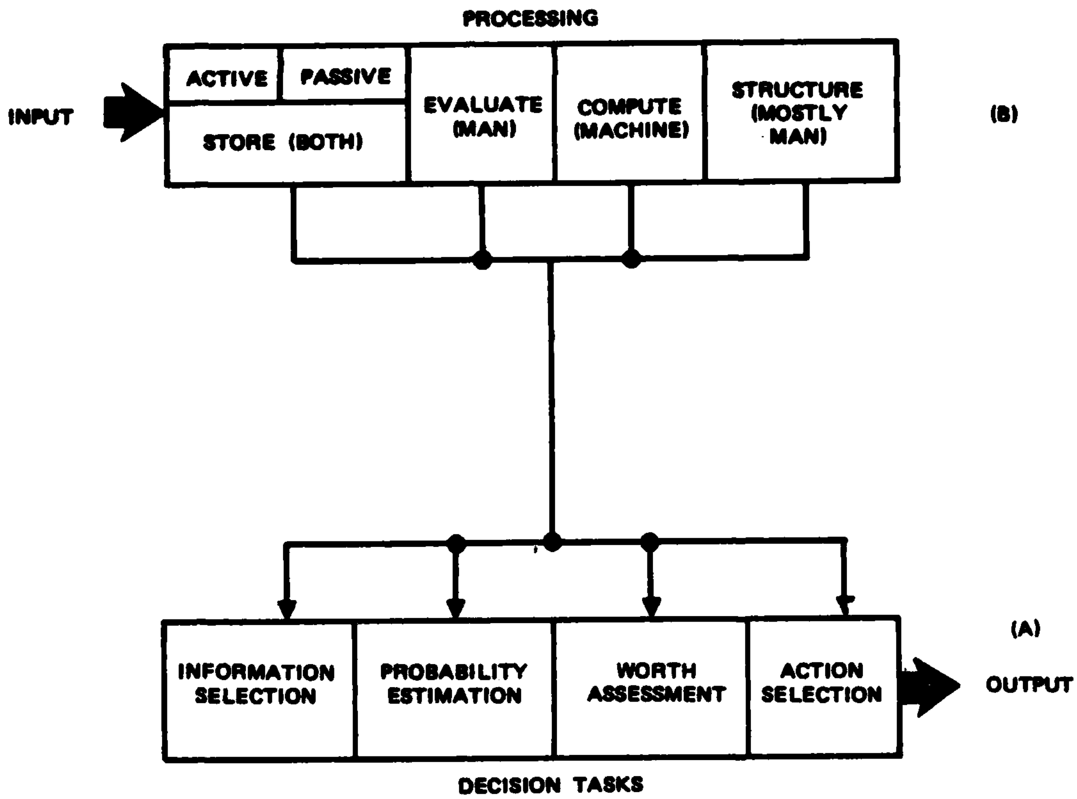

FIGURE A-1. The Relationship Among Processing Requirements and Decision-Making Tasks.

Complex Computational and Modeling Processes

The computing and modeling requirements of decision-aiding have been the focal point of most aiding efforts. One of the earliest aids updated probabilities using operator estimates of current data states as inputs (Domas and Peterson, 1967). Since then, processing algorithms based on queuing theory, pattern recognition, dynamic and nonlinear programming, Bayes theorem, and multiattribute utility (MAUT) models have been used as aids for a variety of tasks (Barnes, 1969; Rouse, 1977).

Evaluation

The assignment of values and priorities to events is usually a human function. This differs from worth assessment in that this processing does not entail generating the final worth function, but rather in assigning value judgments to events. The worth assessment task involves additional processing including structuring the decision situation by listing possible consequences as well as the use of mathematical procedures such as MAUT or multidimensional scaling which model the values elicited from the operator. The final result of these latter processes is a numerical ranking of decision options (Keeney and Raiffa, 1976; Zachery, 1980). However, the numerical rankings for events should reflect the operator's value system and not the mathematical procedure used to model them.

Storage

Active and passive information storage requirements can be handled by both man and machine in decision-aiding situations. This is because the characteristics of computer storage are quite different than those of human storage and each system has its advantages and limitations. In order to maximize decision-aiding performance, the processing and storage characteristics of both the operator and the proposed aid should be used to best advantage.

For example, as mentioned before, the human is best able to evaluate worth. However, human memory and processing are unreliable and inconsistent (Barnes, 1979). An aid that could "capture" the operator's value system without relying on his memorial or computing skills would be very useful. ADDAM, an aid developed by Perceptronics, computes a worth model based on the operator's past preferences and displays the model to the operator. It, in effect, reminds the operator of his own value system and thus eliminates inconsistencies that an operator would normally evince in a repetitive, static environment (Barnes, 1980).

REFERENCES

1. Alluisi, E. A., Muller, P. F. and Fitts, P.M. " An Information Analysis of Verbal and Motor Responses in a Forced-Paced Serial Task," Journal of Experimental Psychology, 1957, v. 56, pp. 153-158.

2. Atkinson, R., Holmgren, J. and Joula, J. "Processing Time As Influenced by Number of Items in a Display," Preception and Psychophysics, 1969, v.6, pp. 329-335.

3. Atkinson, R. and Joula, J. "Factors Influencing Speed and Accuracy of Work Recognition." In S. Korblum (Ed) Attention and Performance IV, New York: Academic Press, 1973.

4. Baddeley, A. D. "Immediate Memory and Perception of Letter Sequences," Quarterly Review of Journal of Experimental Psychology, 1964, v. 16, pp. 364-367.

5. Baddeley, A. D. and Lieberman, K. "Spatial Working Memory." In R. Nickerson, (Ed.), Attention and Performance VIII, Hillsdale, New Jersey: Lawrence Erlbaum, 1980.

6. Barnes, M. J. "Response Selection in Condensation and Selective Reaction Tasks," presented at The Southwestern Psychological Association, Houston, Texas, April 17-19, 1975.

7. Barnes, M. J. "Operator Decision-Making Characteristics," Naval Weapons Center TP 6171, China Lake, California, 1979.

8. Barnes, M. J. "Review of Five Military Decision Aids," Naval Weapons Center TP 6171, China Lake, California, 1980.

9. Briggs, G. and Swanson, J. "Encoding, Decoding and Central Processing in Human Information Processing," Journal of Experimental Psychology, 1970, v. 86, pp. 296-308.

10. Broadbent, D. Decision and Stress, New York: Academic Press, 1971.

11. Cheng, P. W. "A Psychophysical Approach to Form Perception: Incompatibility as an Explanation of Integrality," Human Performance Center TR. 65, University of Michigan, Ann Arbor, Michigan, 1979.

12. Coombs, C. H., Dawes, R. and Tversky, A. Mathematical Psychology: An Elementary Introduction, Englewood Cliffs, New Jersey: Prentice Hall, 1970.

13. Conrad, R., "Acoustic Confusions in Immediate Memory," British Journal of Physchology, 1964, v. 55, pp. 75-84.

14. Conrad, R., Freeman, R. and Hull, A. J. "Acoustic Factors Versus Language Factors in Short Term Memory," Psychonomic Science, 1968, 3, pp. 55-58.

15. Corcoran, D. W. and Rouse, R. "An Aspect of Perceptual Organization Involved in Reading Typed and Handwritten Words," Quarterly Journal of Experimental Psychology, 1970, v. 22.

16. Domas, P. S. and Peterson, C. R. "Probabilistic Information Processing Systems: Evaluation with Conditionally Dependent Data, Organizational Behavior and Human Performance, 1972, v. 7, pp. 77-85.

17. Egeth, H., Jonides, J. and Wall, S. "Parrallel Processing of Multi-Element Displays," Cognitive Psychology, 1972, v. 3, pp. 674-698.

18. Erickson, R. A. "Visual Search Experiment: Noise Persistence, Acuity and Response Time," Journal of Optical Society of America, 1966, v. 56, pp. 491-498.

19. Erikson, C. W. and Spencer, T. "Rate of Information Processing in Visual Perception: Some Results and Methodological Considerations," Journal of Experimental Psychology Monograph, 1969, V. 77, pp. 1-15.

20. Estes, W. K., "Interaction of Symbol and Background Variables in Visual Processing," Perception and Psychophysics, 1972, v. 12, pp. 278-286.

21. Estes, W. K. and Wessel, D. "Reaction Time in Relation to Display Size and Correctness of Response in Forces - Choice Visual Signal Detection," Perception and Psychophysics, 1966, v. 1, pp. 369-373.

22. Fitts, P. M. "Cognitive Aspects of Information Processing 111: Set For Speed Versus Accuracy," Journal of Experimental Psychology, 1966, v. 71, pp. 849-857.

23. Gardner, G. T. "Evidence for Independent Parallel Channels in Tachistoscopic Perception," Cognitive Psychology, 1973, v., pp. 130-155.

24. Garner, W. R. The Processing of Information and Structure. Potomac, Maryland: Lawrence Erlbaum Associates, 1974.

25. Greenwald, A. G. "On Doing Two Things At Once: Time Sharing As a Function of Ideomotor Compatibility." Journal of Experimental Psychology, 1972, v. 94, pp. 52-57.

26. Greenwald, A. G. and Shulman, H. G. "On Doing Two Things at Once: II. Elimination of the Psychological Refractory Period Effect." Journal of Experimental Psychology, 1973, v. 101, pp. 70-76.

27. Hershenson, M. "Verbal Report and Visual Matching Latency as a Function of the Pronouncibility of Letter Arrays." Journal of Experimental Psychology, 1972, v. 96, pp. 104-109.

28. Huebel, D. H. "Integrative Processes in Central Visual Pathways of the CAT." Journal of the Optical Society of America, 1963, v. 53, pp. 58-66.

29. Jones, G. V. "Interaction of Intrinsic and Extrinsic Knowledge," in R. Nickerson (Ed.) Attention and Performance VIII, Hillsdale, New Jersey: Lawrence Erlbaum.

30. Kahneman, D. and Tversky, A. "Subjective Probability: A Judgement of Representativeness." Cognitive Psychology, 1972, v. 3, pp. 430-454.

31. Keeney, R. and Raiffa, H. Decisions with Multiple Objectives. New York: John Wiley and Sons, 1976.

32. Keenan, J. and Baillet, S. "Memory For Personally and Socially Significant Events." In R. Nickenson (Ed.) Attention and Performance VIII, Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1980.

33. Kelley, C. R. Manual and Automatic Control. New York: John Wiley and Sons, 1968.

34. Kling, J. W. and Riggs, L. A. Woodworth and Schlosberg's Experimental Psychology. New York: Holt, Rhinehart and Winston; 1971.

35. Kintsch, W. Semantic Memory: "A Tutorial." In R. Nickerson (Ed.) Attention and Performance VIII. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1980.

36. Krueger L. and Shapiro, R. "Letter Detection with Rapid Serial Visual Presentation: Evidence Against Word Superiority at Feature Extraction." Journal of Experimental Psychology: Human Perception and Performance, 1979, v. 5, pp. 657-673.

37. LaBerge, D. and Samuels, S. J. "Towards a Theory of Automatic Information Processing in Reading," Cognitive Psychology, 1974, v. 6, pp. 293-323.

38. Leal, A. and Pearl, J. "An Interactive Program for Conversational Elicitation of Decision Structures." Proceedings of the IEEE Conference on Systems, Man and Cybernetics, May 1977, v. SMC-7, pp. 368-376.

39. Lehtio, P. K. and Poikonen, L. "Retrieval of Information from a Mental Map." In R. Nickerson (Ed.). Attention and Performance VIII, Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1980.

40. Lehtio, P. K. and Kavri, T. "An Experiment in Mental Scanning." In S. Korblum (Ed.), Attention and Performance IV, New York: Academic Press, 1973.

41. Loftus, G. R. "Acquisition of Information from Rapidly Presented Verbal and Nonverbal Stimuli." Memory and Cognition, 1974, v. 2, pp. 545-548.

42. Liberman, A., Cooper, F., Shankweiker, S. and Studdert-Kennedy. "Perception of a Speech Code," Psychological Review, 1967, v. 74, pp. 1-18.

43. Massaro, D. "Letter Information and Orthographic Context in Work Perception." Journal of Experimental Psychology: Human Perception and Performance. 1979, v. 5, pp. 595-601.

44. Merkhofer, M., Robinson, B. and Korsan, R. A Computer-Aided Decision Structuring Process, TR320, Stanford Research Institute, Menlo Park, CA. 1979.

45. Miller, G. A. "The Magical Number Seven, Plus or Minus 2: Some Limits on Our Capacity for Processing Information." Psychological Review, 1956, v. 63, pp. 81-97.

46. Mocharnuk, J. B. Human Factors, Visual Target Acquisition and Ocular Scanning Performance, v. 20, 1978, pp. 611-631.

47. Morton, J. "Interaction of Information in Word Recognition," Psychological Review, 1969, v. 76, pp. 165-178.

48. Murdock, B. M. "Short-Term Recognition Memory." In R. Nickerson (Ed.). Attention and Performance VIII. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1980.

49. Neisser, V. "Visual Search." Scientific American, 1964, v. 210, pp. 94-102.

50. Neisser, V. Cognitive Psychology. New York: Appleton, 1967.

51. Norman, D. A. "Toward a Theory of Memory and Attention." Psychological Review, 1968, vol. 75, pp. 522-536.

52. Norman, D. A. Memory and Attention: An Introduction to Human Information Processing. New York: John Wiley and Sons, 1969.

53. Norman, D. A. "Learning and Remembering: A Tutorial Preview." In (Ed. S. Korblum). Attention and Performance IV. New York: Academic Press, 1973.

54. Pachella, R. G. "The Interpretation of Reaction Time in Information Processing Research." In B. Kantowitz (Ed.). Human Information Processing: Tutorials in Performance and Cognition. Hillsdale, New Jersey: Lawrence Erlbaun Associates, 1974.

55. Posner, M. "Short Term Memory Systems in Human Information Processing." Acta Psychologica. 1967, v. 27, pp. 267-284.

56. Posner, M., Boies, S., Eichelman, W. and Taylor, R. "Retention of Visual and Name Codes of Single Letters." Journal of Experimental Psychology Monograph, 1969, v. 79, pp. 1-16.

57. Posner, M. and Klien, R. "On the Functions of Consciousness." In S. Korblum (Ed.). Attention and Performance TV, New York: Academic Press, 1973.

58. Rabbit, P. and Vyas, S. "What is Repeated in the "Repetition Effect"?" In S. Korblum (Ed.). Attention and Performance IV, New York: Academic Press, 1973.

59. Reicher, G. M. "Perceptual Recognition as a Function of Meaningfulness of Stimulus Material." Journal of Experimental Psychology, 1969, v. 81, pp. 275-280.

60. Rumelhart, P. "A Multicomponent Model of the Perception of Briefly Exposed Visual Displays." Journal of Mathematical Psychology, 1970, v. 7, pp. 191-218.

61. Sanders, A. F. Some Remarks on Mental Load, paper from Institute For Perception, Soesterberg, The Netherlands, 1980.

62. Sanders, A. F. and Moss, S., "The Effects of Input Modality and Vocalization on Intratrial Rehearsal." In S. Korlum (Ed.). Attention and Performance IV, New York: Academic Press, 1973.

63. Schvaneveldt, R. W. and Meyer, D. E. "Retrieval and Comparision Processes in Semantic Memory." In S. Korblum (Ed.). Attention and Performance IV, New York: Academic Press, 1973.

64. Smith, E. E. and Spoehr, K. T., "The Perception of Printed English: A Theoretical Perspective," In B. Kantowitz (Ed.). Human Information Processing: Tutorials in Performance and Cognition, Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1974.

65. Sokolov, Y. N., Perception and the Conditioned Reflex, Oxford: Pergamon Press, 1963.

66. Somers, P. Perceptual Interaction Between Stimulus Dimensions as a Basis of Dimensional Integrity. Human Performance Center TR No. 61, Ann Arbor, Michigan, University of Michigan, 1978.

67. Sperling, G. "The Information Available in Brief Visual Presentations." Journal of Experimental Psychology Monograph, 1960, v. 74, pp. 1-29.

68. Sperling, G. "A Model for Visual Memory Tasks in the Proceedings." Symposium on Information Processing, Los Angeles, California, University of Southern California, June 23, 1962.

69. Sternberg, S. "High Speed Scanning in Memory," Science, 1966, v. 153, pp. 652-654.

70. Sternberg, S. "Two Operations in Character Recognition: Some Evidence from Reaction Time Measurements." Perception and Psychophysics, 1967, v. 2, pp. 45-53.

71. Sternberg, S. "The Discovery of Processing Stages: Extensions of Donder's Method. Acta Psychologica, 1969, v. 30, pp. 276-315.

72. Swanson, J. M. and Briggs, G. E. "Information Processing as a Function of Speed versus Accuracy." Journal of Experimental Psychology, 1969, v. 81, pp. 223-239.

73. Swensson, R. G. "The Elusive Tradeoff: Speed Versus Accuracy in Visual Discrimination Tasks." Perception and Psychophysics, 1972, vol. 12, pp. 16-32.

74. Teichner, W. H. Quantitative Models for Predicting Human Visual/Perceptual/Motor Performance, Las Cruces, New Mexico: New Mexico State Technical Report 74-3, 1974.

75. Teichner, W. H. and Krebs, M. J. "Laws of Visual Choice Reaction Time." Psychological Review, 1974, v. 81, pp. 15-28.

76. Teichner, W. H. and Mocharnuk, J. B. "Visual Search for Complex Targets." Human Factors, 1979, v. 21, p. 259.

77. Townsend, J. T. "Issues and Models Concerning the Processing of Finite Number of Inputs." In B. Kantowitz (Ed.). Human Information Processing: Tutorials in Performance and Cognition, Hillsdale, New Jersey: Lawrence Erlbaun Associates, 1974.

78. Venesky, R. L. "English Orthography: Its Graphical Structure and Its Relation to Sound." Reading Research Quarterly, 1967, v. 2, pp. 75-106.

79. Wheller, D. D. "Processes in Word Recognition," Cognitive Psychology, 1970, v. 1, pp. 59-85.

80. Yellott, J. I. "Correction For Fast Guessing and the Speed-Accuracy Tradeoff." Journal of Mathematical Psychology, 1971, v. 8, pp. 159-199.

81. Zachery, W. Applications of Multidimensional Scaling to Decision Situation Prioritization and Decision Aid Design, Willow Grove, Pennsylvania, Analytics Technical Report 1366-B, 1980.